FASCODE for the Environment (FASE)

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The Optical Physics Division of the Air Force Phillips Laboratory with support from the Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Program is developing a state-of-the-art line-by-line atmospheric radiative transfer model as the successor to FASCODE (Fast Atmospheric Transmittance Code). The goal of this project is to create a computationally efficient model which contains the most up-to-date physics. The new model, known as FASCODE for the Environment, or "FASE", combines the best features of FASCODE and LBLRTM (Line-by-Line Radiative Transfer Model), the DOE's standard radiative transfer model. Upgrades to FASE include the addition of a solar spectrum module to compute the attenuated, line-of-sight solar radiance, improvement of the cloud and aerosol descriptors, based on changes made to MODTRAN (Moderate Resolution Transmittance Model), and the ability to incorporate the new heavy molecule absorption cross-section data found on the HITRAN96 database, which is of slightly different format from the previous HITRAN cross-section data. This paper addresses changes which have been made to FASCODE and LBLRTM to create FASE, and gives an overview of the new capabilities and recent model validations.

The ability to accurately model radiation propagating through the atmosphere requires the continual development of existing models, especially as measurement techniques and instrumentation become more sophisticated. The joint US Air Force (USAF) and Department of Energy Atmospheric Radiation Measurement program (DOE-ARM) line-by-line radiative transfer model "FASE" is the latest in the FASCODE[1] series of line-by-line models. FASE is grounded in FASCOD32, with important contributions from FASCOD3P, the USAF band model MODTRAN[3], and the standard DOE line-by-line model LBLRTM[4]. Once the initial development and beta-testing of FASE are complete, the code will be re-named FASCOD4. This manuscript gives an overview of FASE and addresses future development issues.

The core of FASE consists of the FASCODE lineshape algorithms. After FASCOD3, parallel development funded by DoD and DOE resulted in the creation of FASCOD3P and LBLRTM. These codes, separately, made a number of advances over FASCOD3. As it became clear that DoD would benefit from specific advances in LBLRTM, the FASE effort was initiated to merge FASCOD3P and LBLRTM. Since a number of FASCOD3 features were not required for the DOE-ARM community (e.g. the non-local thermodynamic equilibrium routines), they were eliminated. However, the advances for LBLRTM resulted in significant changes to the core modules which compute the layer optical depth, as well as vectorization and pararneterization of the entire code. Thus a thorough evaluation of the two codes was necessary to determine the best way to create FASE: by transferring the changes directly to FASCOD3P, or by starting with LBLRTM and adding the routines that were dropped. It was found that the most expedient method would be to start with LBLRTM and add the features from FASCOD3P[6]. This effort was undertaken only after it was established that the optical depth calculations of both codes gave results that differed by less than 1% for a set of standard test cases[7].

The most significant changes to FASCOD3 found in LBLRTM are vectorization of the code to significantly decrease the run-time of the model, modifications to increase the accuracy of the Voigt lineshape function, and parameterization of array dimensions. The vectorization and parameterization changes involved both there-writing of portions of the code to eliminate “if-then” tests from within “do-loops”, as well as a general cleaning of the code to improve user accessibility. The change in the sampling of the Voigt lineshape was made to increase the mathematical accuracy of the optical depth calculations to less than 0.59”. This change was prompted by advances in sensor technology which enable measurements to be made with very high spectral resolution. Table 1 lists the changes to FASE which originated in LBLRTM.

Table 1: FASE Features from LBLRTM

•vectorization and pararneterization of the code	● improved accuracy of the Voigt lineshape
● 2020 cm- 1 calculation spectral range	● embedded FFT scanning functions
● alternate 02 line coupling in microwave scaled to agree with data	“alternate C02 line coupling in thermal infrared scaled to attain agreement with data
● option: fixed wavenumber grid output for all layers driven by the smallest sample value	● option: layer optical depth in separate files for compatibility with external multiple scattering codes

NEW FEATURES

In addition to upgrades of existing features, several new features were added to FASE. These are listed in Table 2. Of particular significance are the addition of the solar spectrum module and upgrades to the aerosol, cloud and rain routines. Also, FASE has been updated to accept all of the molecular and atomic species on the HITRAN96[9] database.

Table 2: Partial List of New FASE Features

● solar spectrum module	● updated aerosol, cloud, and rain module
● fully compatible with HITRAN96	● external file for emissivity and reflectivity coefficients
● Schumann-Runge bands and continuum	‘updated coefficients for Hartley-Huggins band
● corrections to the spherical geometry algorithm	● corrections to the NLTE routines
● option: layer input in 'atm-cm'	● check for required line coupling coefficients

The solar spectrum module allows the user to compute the attenuated solar irradiance. This can be either along a direct line-of-sight, or a line-of-sight that involves surface reflection. The default solar spectrum has two components[10,11], one from 50-50000 cm^{-1}, and the other from 50000-57500 cm^{-1}. The spectra are stored in unformatted data files which allows the user to use an alternative spectrum with minimal effort. As a time saving measure, FASE has an option to write the attenuated radiance to a separate file. This enables the user to do a number of calculations with, for example, different surface reflection properties, without having to re-compute the attenuated solar radiance.

The routines to compute the spectral properties of aerosols and hydrometers (including clouds and rain) are part of a module adopted from LOWTRAN12 prior to FASCOD3. The changes to the module in FASE reflect changes that were made for MODTRAN (version 3.5)[13]. In particular, these routines are now able to simulate mixed phase cloud types as well as multiple cloud decks. Further, with the new routines it is much easier for the user to specify and simulate the spectral and microphysical properties of a particular type of cloud.

The latest version of the HITRAN spectroscopic database, HITRAN96, has been expanded to include a total of 36 molecular species. The FASE array sizes and atmospheric input specifications have been updated to accommodate all of these species. HITRAN96 also contains new values for the absorption cross-sections of heavy-molecules (e.g. CFCs) based on the work of Varanasi[14]. Since these cross-sections are given as a function of pressure and temperature, they must be used in a different fashion than the previous cross-section files, which were only a function of temperature. Rather than interpolating or extrapolating the tabulated values to the pressure/temperature combination required for a calculation, Toon and Sen[15] created a set of ‘pseudo-lines’ for these species, allowing the calculations to be done in the same manner as the line-by-line calculation. The pseudo-lines were created by fitting a set of equally-spaced spectral lines to the cross-sectional data to create a line file similar to the HITRAN format. The least-squares fit was done for the line strength, halfwidth, and lower state energy, and the resulting series of lines can be merged directly with lines selected from the HITRAN database. The pseudo-line fits from Toon and Sen cover also some measurements not on the HITRAN96 database. The pseudo-line file is part of the FASE databases, and can easily be changed as new species or alternative fits become available.

An example of a calculation with the heavy-molecule cross-sections is given in Figure 1. The lower curve shows the spectrum without CFCs, while the upper curves show the spectrum with current levels of CFCs, and with the CFC levels that can be expected by 2002. It is clear that accurate simulation of these species is required if the 8-12 μm widow region is to be utilized for the quantitative information required for the sensing of boundary and cloud properties, as well as for surveillance applications. It should be noted that the calculation without CFCS represents that which would be calculated by LOWTRAN, which does not have any CFC species in its band model.

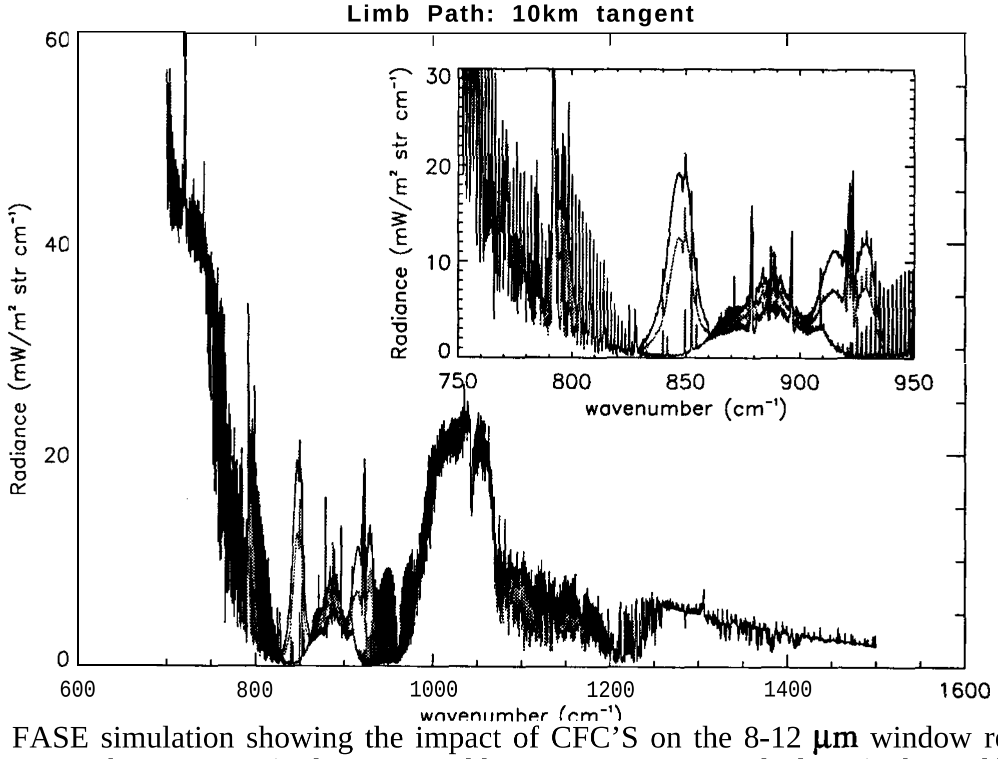

Figure 1: FASE simulation showing the impact of CFC'S on the 8-12 μm window region. The lower curve is without CFC'S (and is comparable to a LOWTRAN calculation), the middle curve is with current CFC levels, and the upper curve is with the CFC levels anticipated for the year 2002. Note that the levels of H20 (e.g. 700-800 cm^{-1}), HN03 (870 -900 cm^{-1}), and 03 (1000 - 1050 cm^{-1}) were kept constant for this simulation.

CURRENT AND FUTURE FASE/FASCODE DEVELOPMENT

Current work on FASE involves the addition of the FASCODE multiple scattering routines. FASE has an input option whereby the layer optical depth information necessary for a stand-alone multiple-scattering program will be written to a series of data files. Currently the output file format is that required for input to the multiple-scattering programs CHARTS [16] and DISORT[17]. The FASCODE routines contain a 2-stream approximation to the scattering[18] and are useful for low-scattering atmospheres, or relatively fast, preliminary calculations in a given spectral band. Once the 2-stream multiple-scattering has been implemented in FASE, the code will have all of the original capabilities of FASCOD3P. At that point is will be re-named FASCOD4 and will be made available from the Air Force with DOE consent.

It is anticipated that future upgrades to FASCOD4 will include (1) the ability to compute the single-scattered solar radiance, and (2) the addition of the Herzberg bands in the 240-280 nm region of the UV. The single-scattered solar radiation is an important component to the radiance in the near infrared. The fact that this is not included in the current state-of-the-art LBL model could lead to serious errors in near-infrared calculations under sunlit conditions. The inclusion of the Herzberg bands is important in the solar blind region, which is often used for UV communications and sensors. As with single-scattering, the lack of this information in LBL models could have serious consequences.

"Hyperspectral sensing" is a relatively new descriptor for nadir-viewing measurement techniques historically used by the atmospheric remote sensing communities. As opposed to "multi-spectral" sensing, which includes any instrument with a finite number of specific channels, filters, or bands, hyperspectral implies employing enough channels, usually contiguous, to provide information sufficient to de-correlate the spectral characteristics of the surface and the atmosphere. This definition[19] can be contrasted with others, such as "any instrument with better than 4 cm^{-1} resolution used for surveillance. "[20] The latter definition can be entirely inadequate in the thermal infrared (TIR) because overlapping molecular systems will not be sufficiently discriminated at such low spectral resolution. However, in the visible and near-infrared regions of the spectrum, a typical wavelength resolution of 10 nm at 600 nm, e.g., that employed by the AVIRIS instrument for the airborne sensing of surface properties[21], corresponds to a wavenumber resolution of over 200 cm^{-1}, and the 4 cm^{-1} "hyperspectral resolution" is more than sufficient to separate the atmospheric and surface contributions to the radiance.

While the definition of hyperspectral sensing typically refers only to nadir-viewing instruments, the concept can be expanded to limb- and zenith-viewing instruments as well. In these cases, high spectral resolution in the infrared is required to achieve high vertical resolution and to aid in de-correlating contributions from the atmosphere and clouds. Because FASCODE calculations are at monochromatic spectral resolution, FASCODE can be used for TIR hyperspectral sensing. In fact, the FASCODE algorithm has been used extensively to compute the atmospheric compensation for interferometer data taken from ground, aircraft and satellite platforms[22,23]. One drawback of line-by-line models is the amount of time required for computation, and the use of FASCODE for operational hyperspectral sensing will require time-saving modifications to the code. A number of approaches to this problem are being tested and evaluated[24].

MODEL VALIDATIONS

Validation of FASCODE is an on-going process involving the comparison of calculations with measured spectra. This exercise requires accurate knowledge of the atmospheric profile in order to separate differences due to the atmospheric path from differences due to the algorithm itself. Recently, validation of data from the High-resolution Interferometer Sounder (HIS)[25] showed that FASCOD3P is capable of fitting the measurements within a few percent, given accurate sonde data. This work also showed that, independent of sonde information, the high resolution measurements were able to reveal the state of the atmosphere and allow the determination of sea surface albedo and temperature. When applied to hyperspectral imaging this process is termed ‘atmospheric compensation’.

CONCLUSIONS

The Air Force Phillips Laboratory development of high spectral resolution radiative transfer models continues with the merger between FASCOD3P and LBLRTM to create FASE, which will ultimately become FASCOD4. A number of new features have been added to FASE, the most notable of which are the ability to compute the attenuated solar radiance, the ability to use all the species on the HITRAN96 database, and major improvements to the cloud/rain routines. These features greatly expand the capabilities of the model and allow for realistic simulations of the atmospheric radiation environment.

While they are often thought of as slow and cumbersome, line-by-line models such as FASCODE play an important role in the development of faster radiative transfer models. The ability of these codes to compute the fundamental physics is an important link between the fundamental radiative transfer and the fast model approximations. Because of its breadth, covering the microwave to the ultraviolet under LTE and NLTE conditions with a spherical path geometry algorithm, FASCODE will play a key role in the development and validation of fast algorithms applicable to real-time hyperspectral sensing and imaging.

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